Paper ID: 5206

CASCADED ALL-PASS FILTERS WITH RANDOMIZED CENTER FREQUENCIES AND PHASE POLARITY FOR ACOUSTIC AND SPEECH MEASUREMENT AND DATA AUGMENTATION

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CAPRICEP

wakayama univ.

GitHub

Resource

YouTube

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Take home message

A new Time-Stretched-Pulse provides a solid foundation of acoustic measurements

- **Motivation:** Measure and record speech data acquisition and presentation conditions
- **Issues:** The target (real-world) systems consist of not only linear time-invariant but also non-linear time-invariant, random, and time-varying responses
- **Solution:** We invented a simultaneous measurement of multiple paths by combining extended TSP signals with binary orthogonal weight sequences
- **Solid foundation:** Cascading all-pass filters with randomized center frequencies and phase polarity yields an extended TSP, called **CAPRICEP**
- **Example application:** We open-sourced an interactive and real-time tool

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An impulse response represents the behavior of any linear time-invariant system


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In reality, linear time-invariance is an approximation of acoustic systems. The impulse is not applicable

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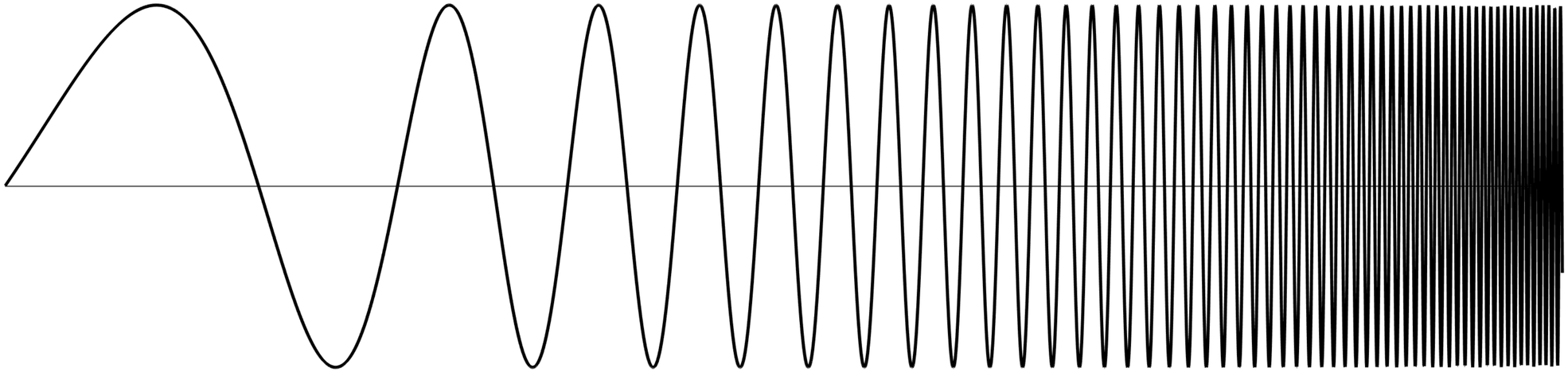
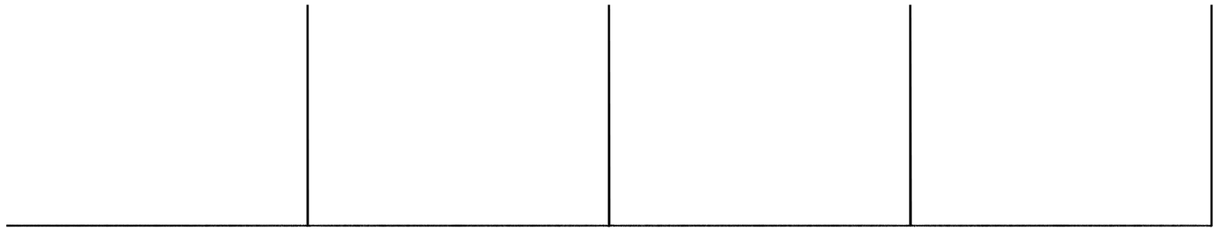
TSP(1): Swept-sine

Sweeping frequency yields a time stretched pulse



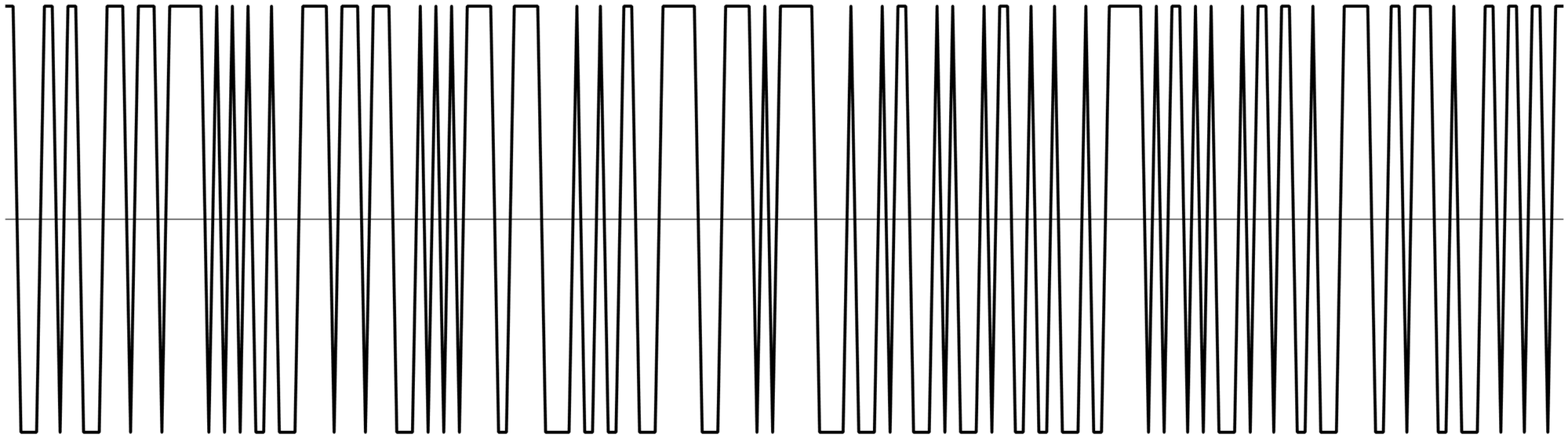
sample sound



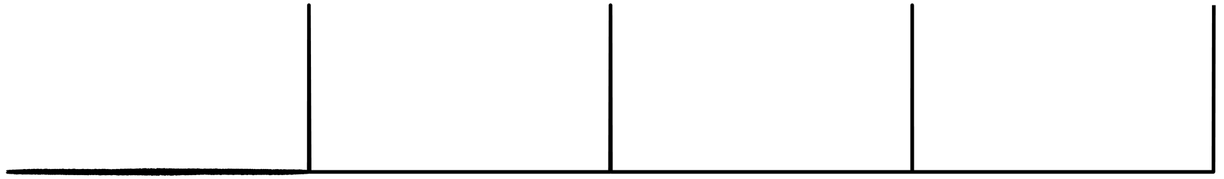
Four repetition convolved with the time-reversed one

TSP(2): MLS, Maximum Length Sequence

Periodic pseudo random sequence yields a time stretched pulse



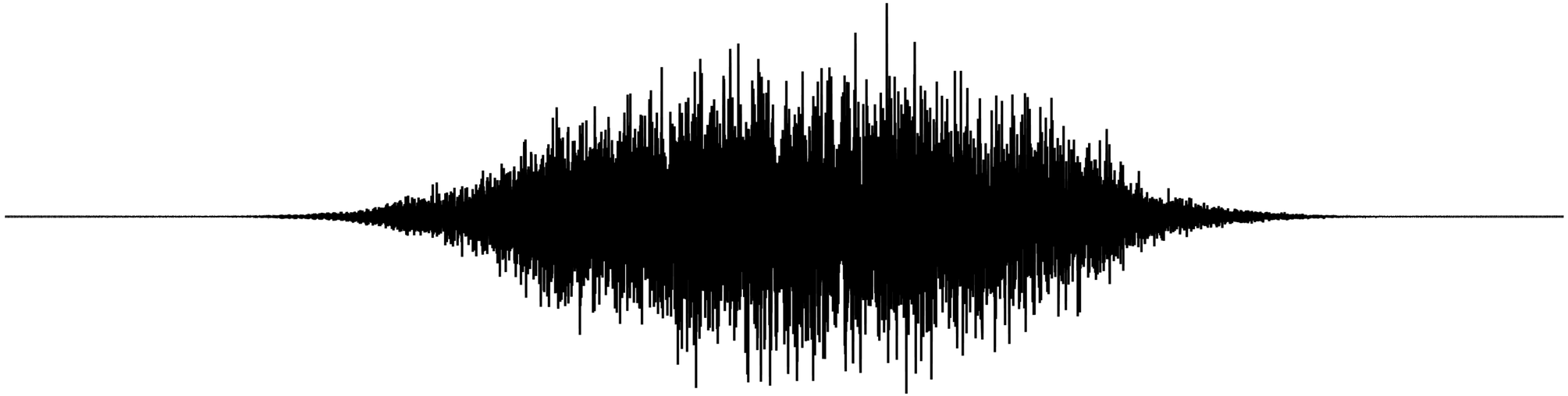
sample sound



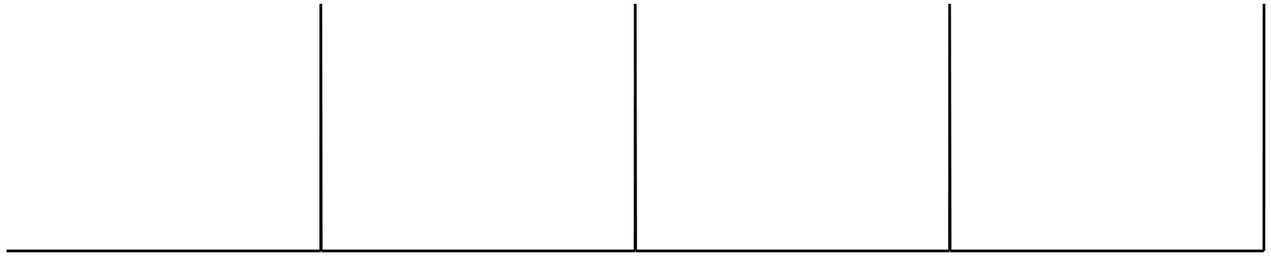
Four repetition convolved with the time-reversed one

TSP(3): CAPRICEP, our proposed signal

Cascaded all-pass filters ALSO yields another time stretched pulse



sample sound



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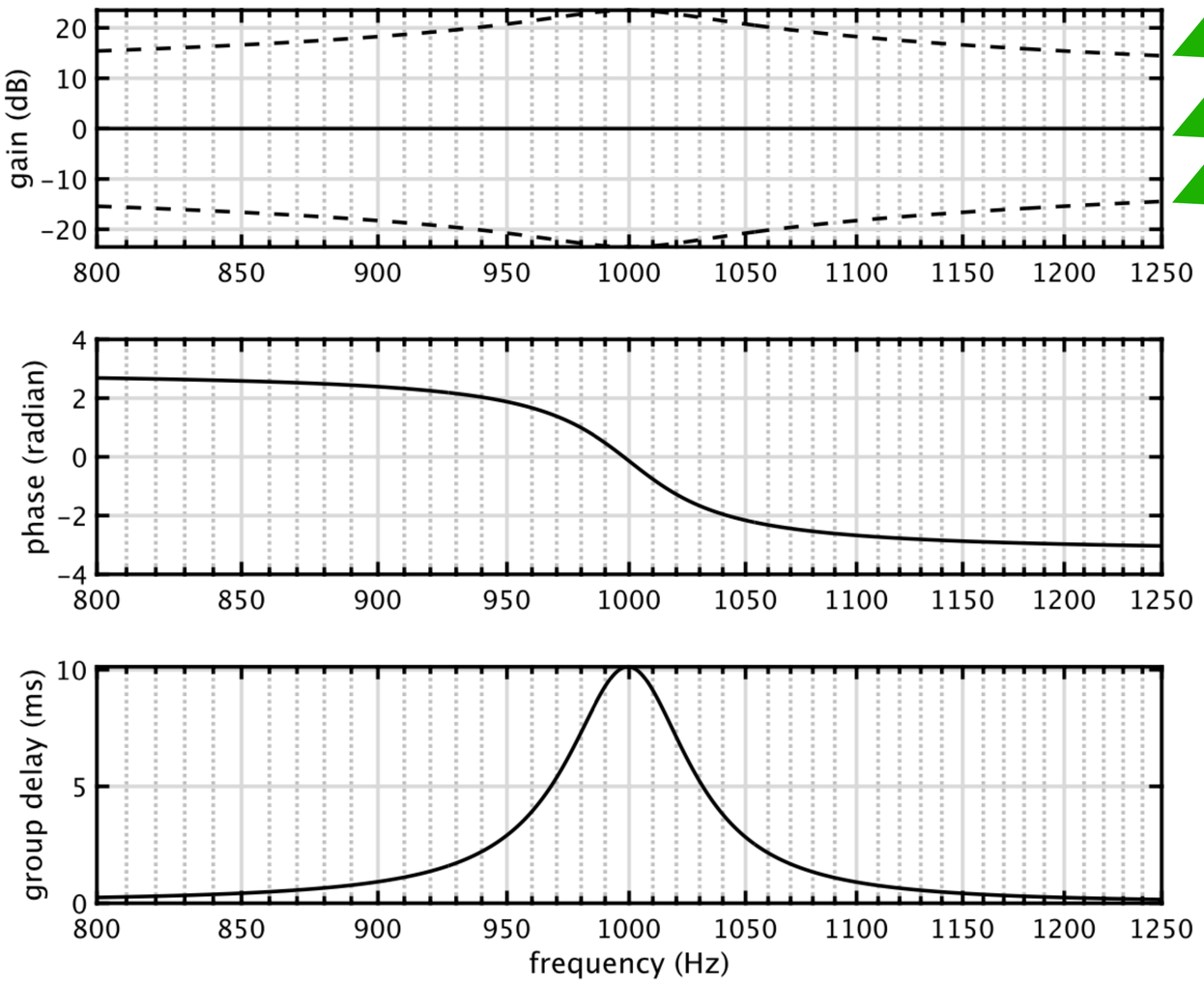
All-pass filter: a building unit

Example: center frequency 1000Hz, bandwidth 20Hz



Gain by denominator (pole)

Cancelling yields constant gain

Gain by numerator (zero)

$$H_k(z) = \frac{z^{-1} - z_k^*}{1 - z_k z^{-1}}, \qquad \left(\text{where: } H_k^*(z)H_k(z) = 1\right)$$

$$z_k = \exp\left(-\frac{\pi b_k}{f_s} + j\frac{2\pi f_k}{f_s}\right)$$

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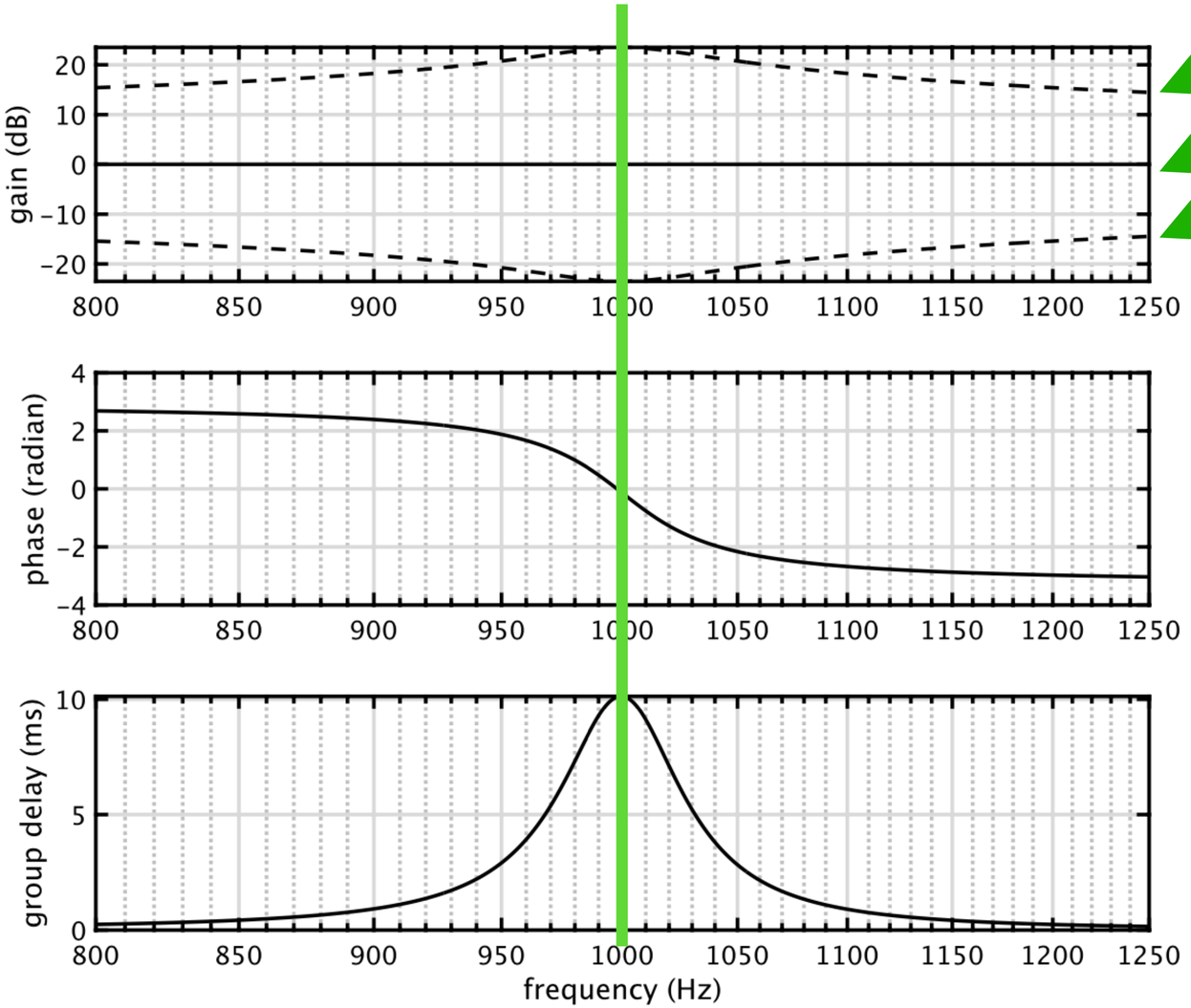

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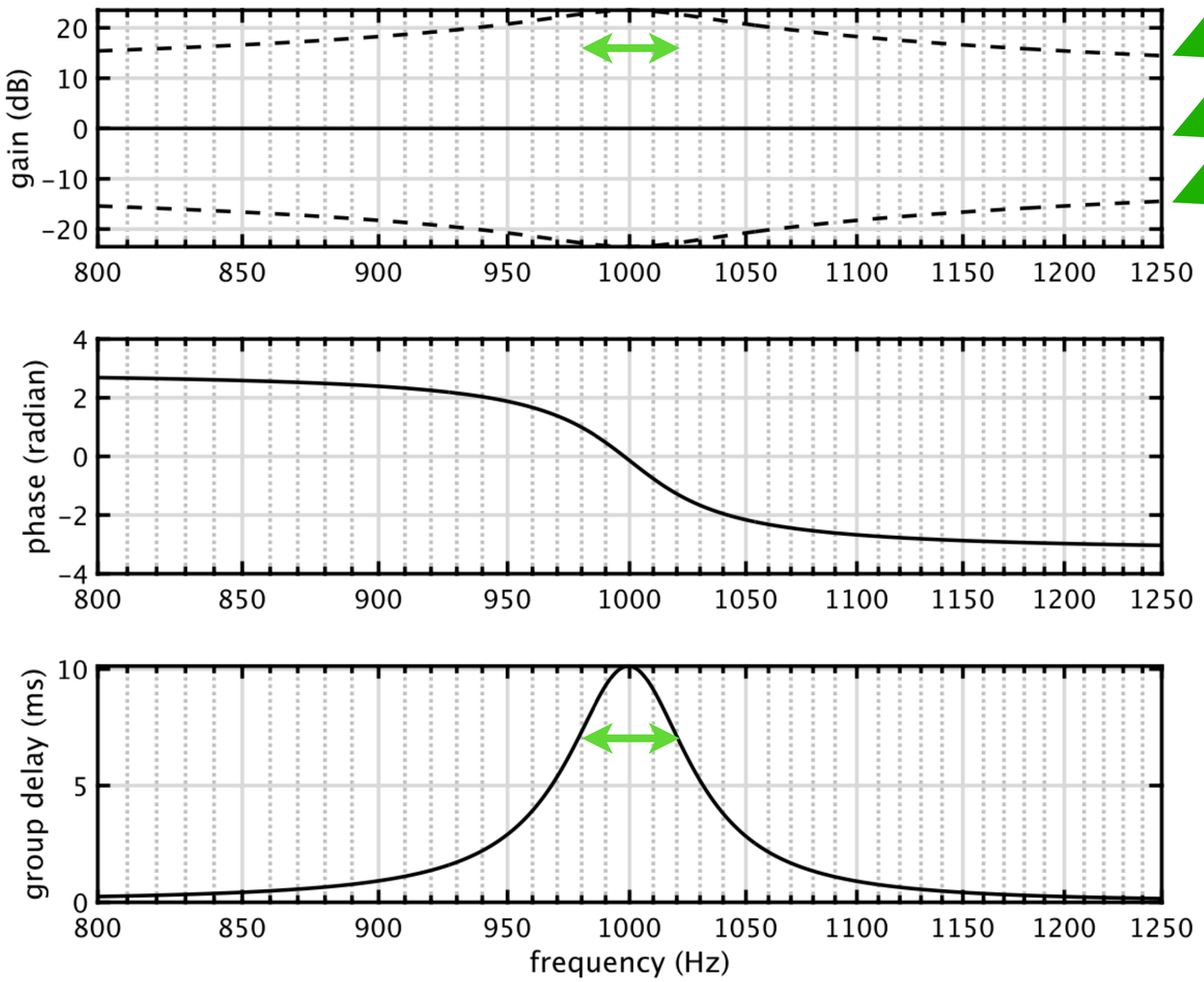

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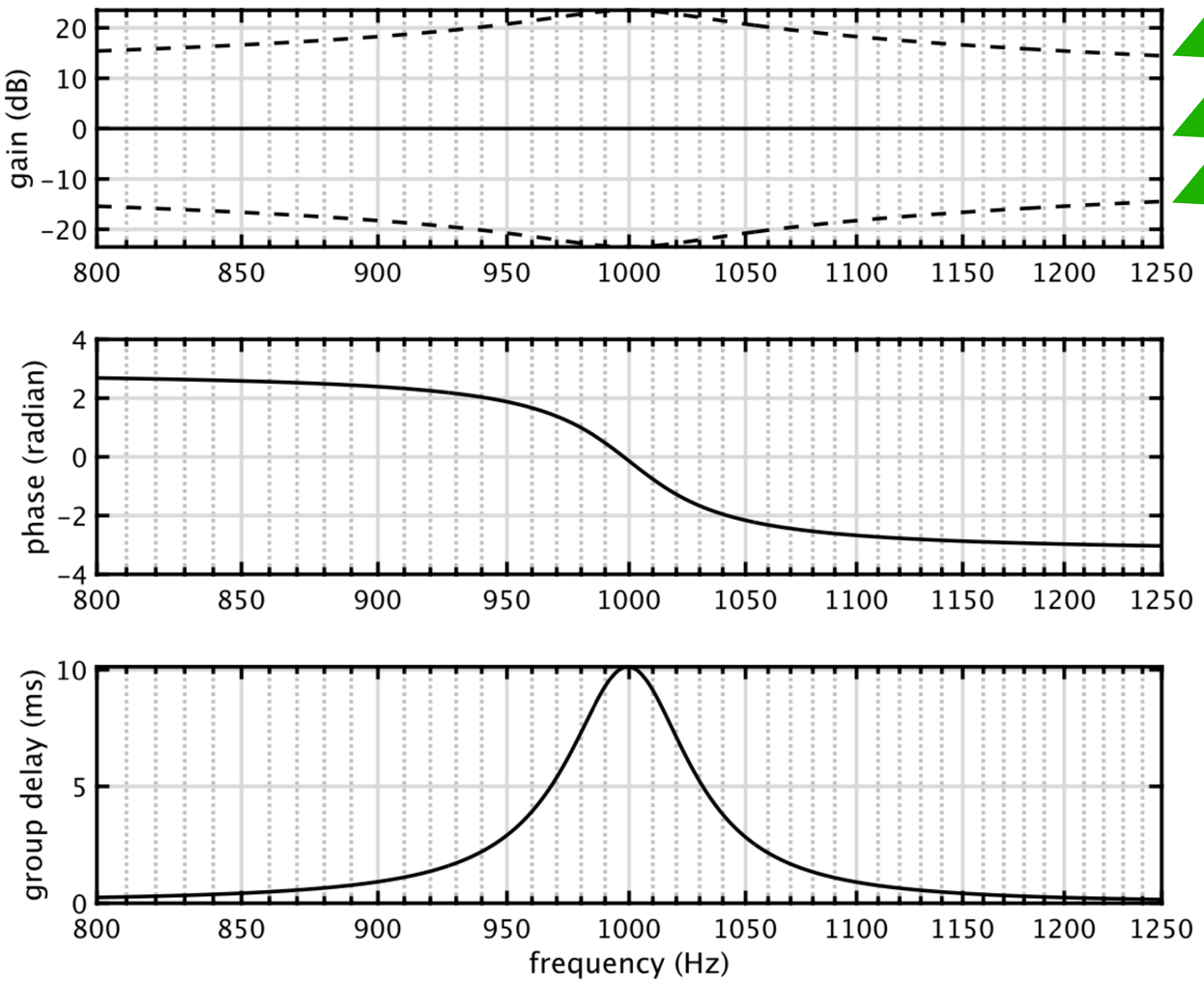


Gain by denominator (pole)

Cancelling yields constant gain

Gain by numerator (zero)

Cascading all-pass filters yields another all-pass filter

$$H_k(z) = \frac{z^{-1} - z_k^*}{1 - z_k z^{-1}}, \qquad \left(\text{where: } H_k^*(z) H_k(z) = 1\right)$$

$$z_k = \exp\left(-\frac{\pi b_k}{f_s} + j\frac{2\pi f_k}{f_s}\right)$$

Design goal of the extended TSP

How to design each all-pass filter

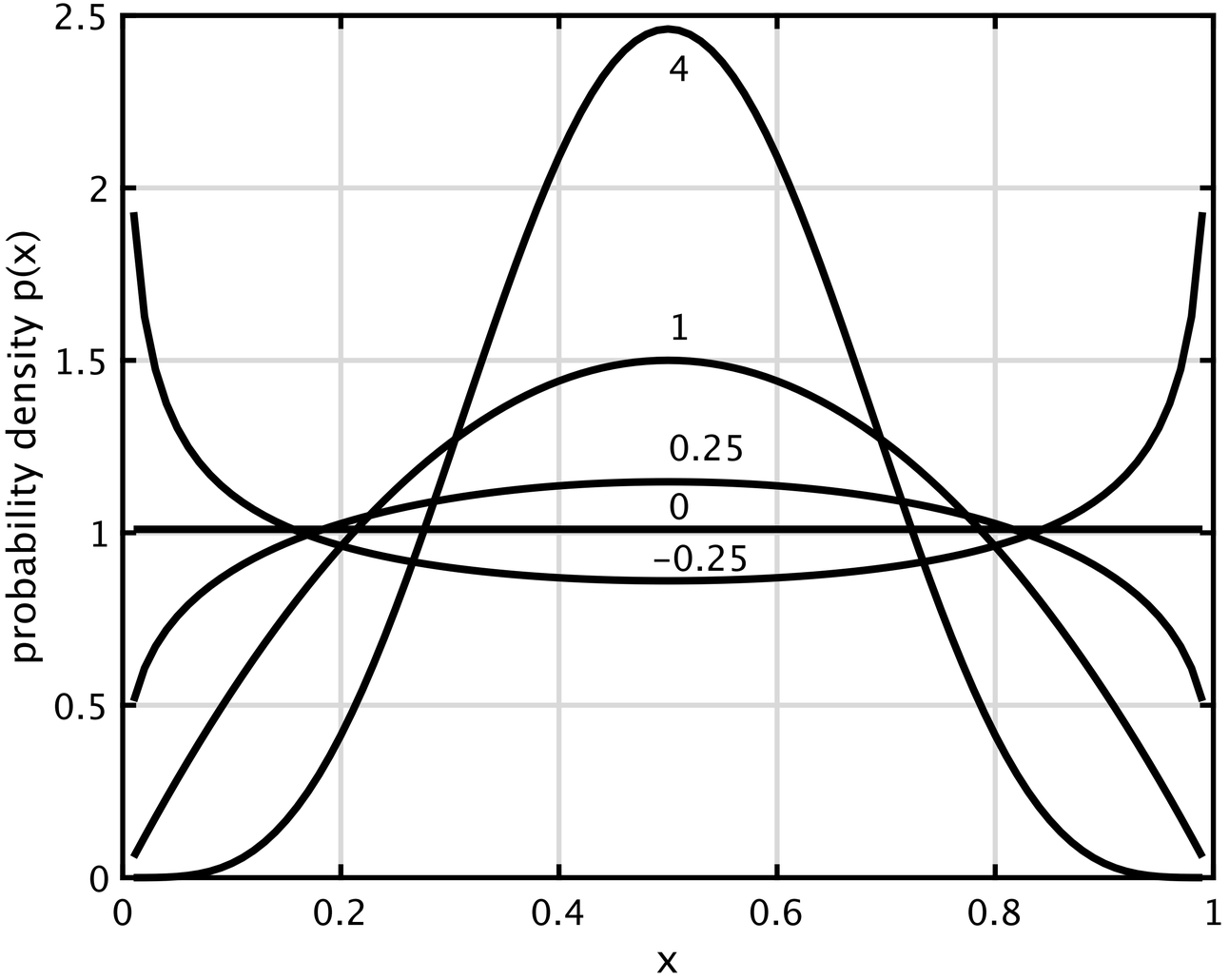
- Impulse response (time domain representation) should be localized
- We need to design the duration and the shape of distribution

  by using …

- two random numbers to set the center frequency and the phase polarity

Randomize distance between center frequencies

Beta distribution provides design freedom



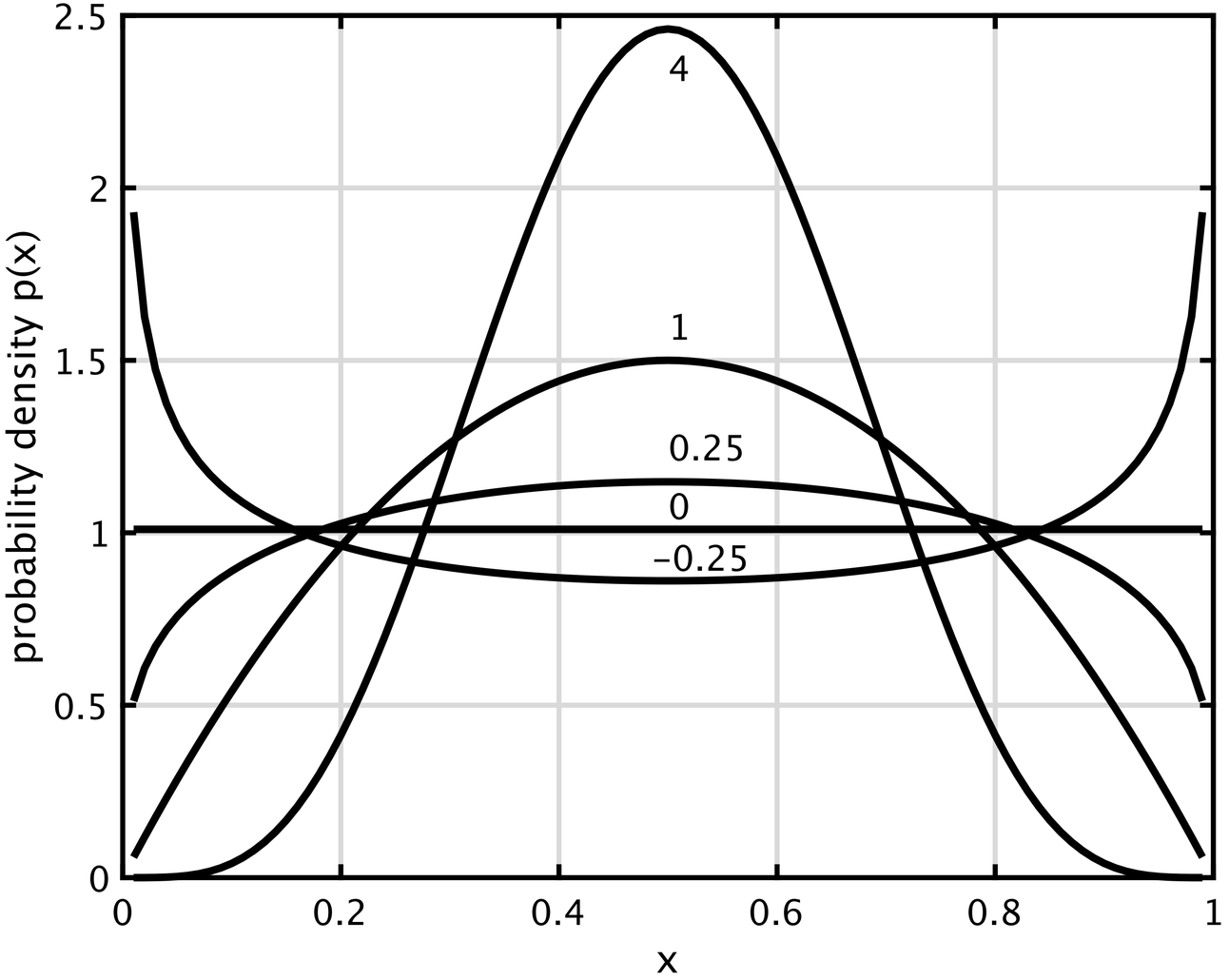
$$f_k = r_1[k]\, F_d \sum_{k=1}^{K} r_2[k]$$

$$b(x) = \frac{x^{\alpha-1}(1-x)^{\beta-1}\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}$$

This time, for simplicity, we set $\alpha \equiv \beta$

Randomize the polarity of the phase

Polarity inversion reverses the time axis of the response



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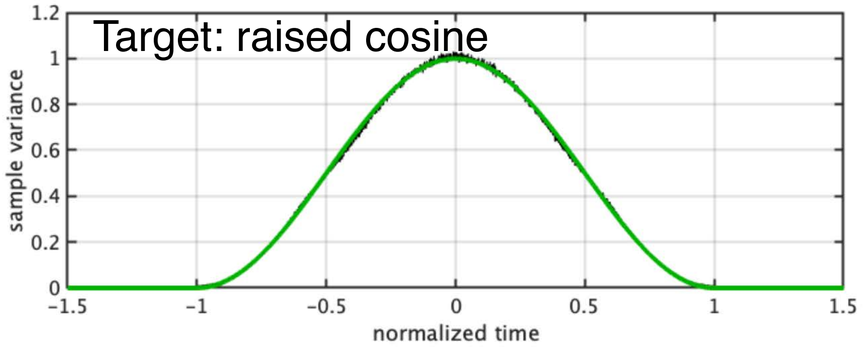
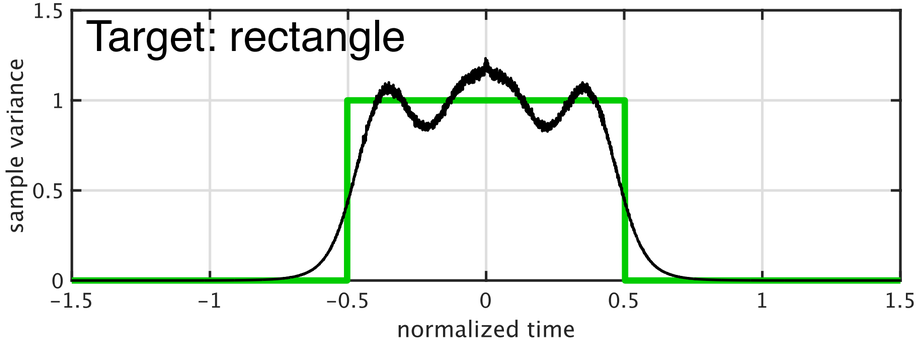
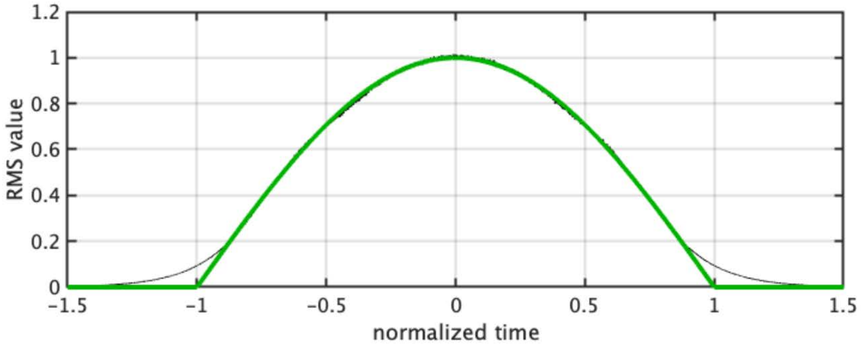
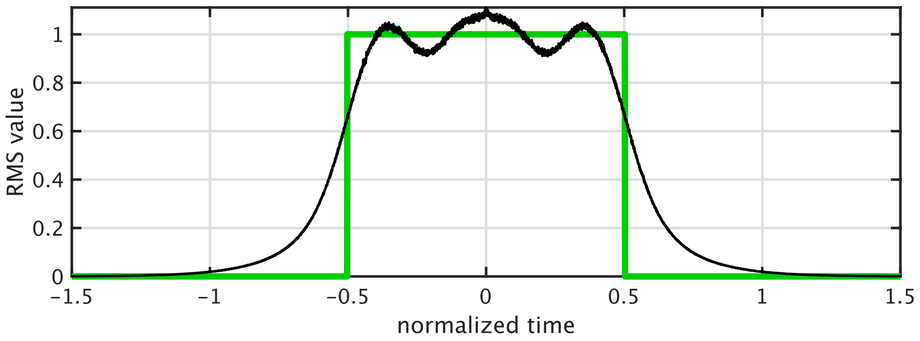
Shape design examples

Using Wasserstein measure

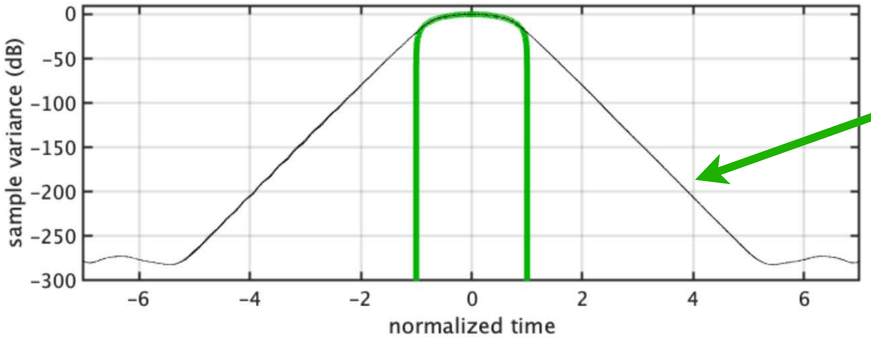


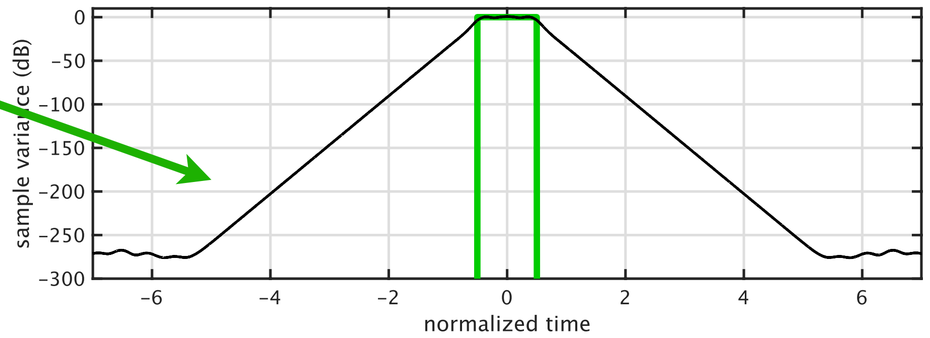






Exponential decay localizes well

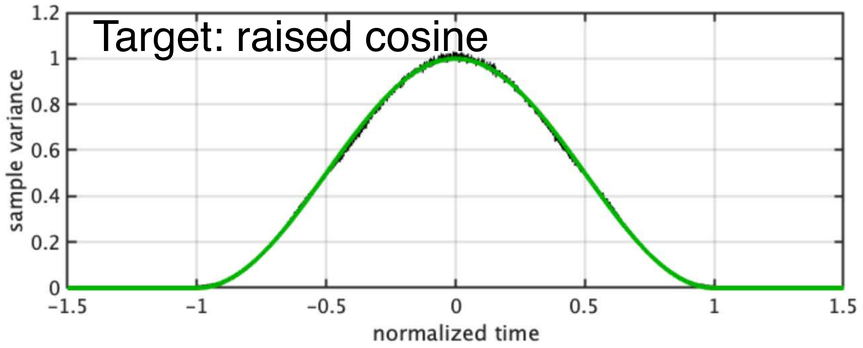


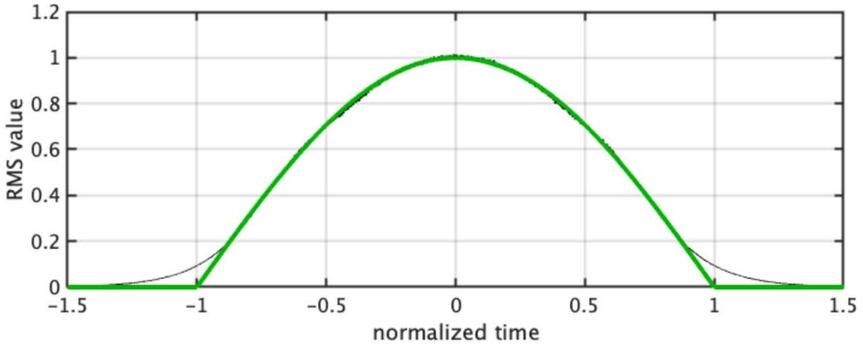


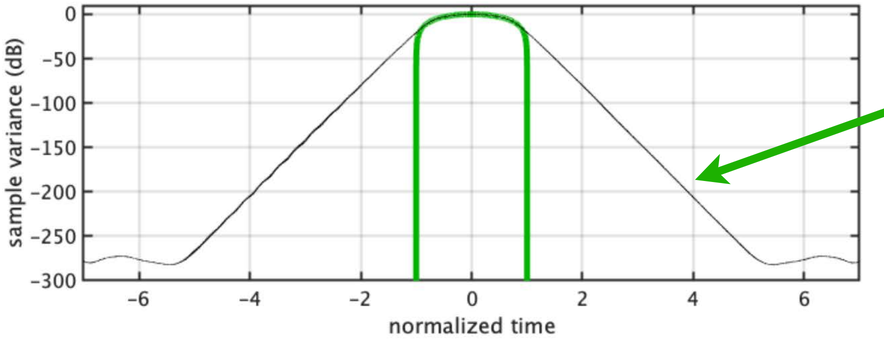
Shape design examples

Using Wasserstein measure

More than thousands design parameters provides flexibility, and independence between TSPs
→ simultaneous multi-path measurement







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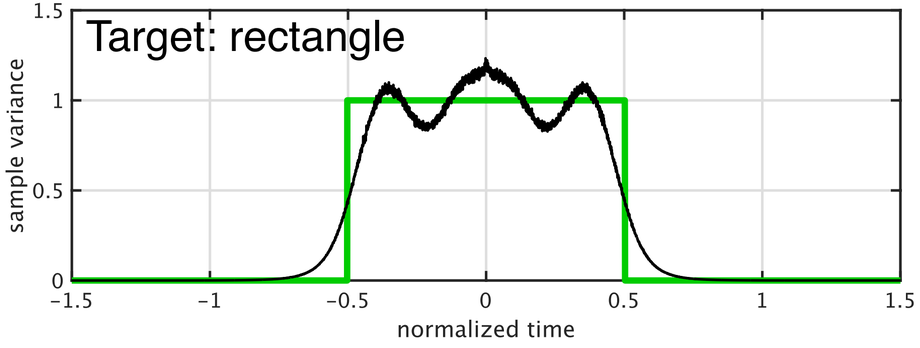

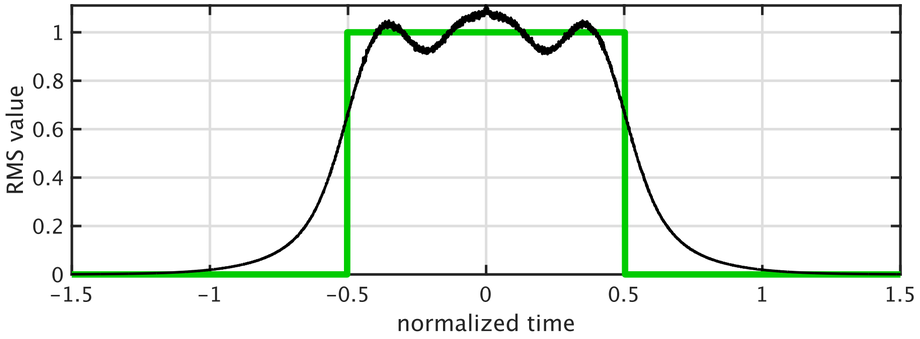

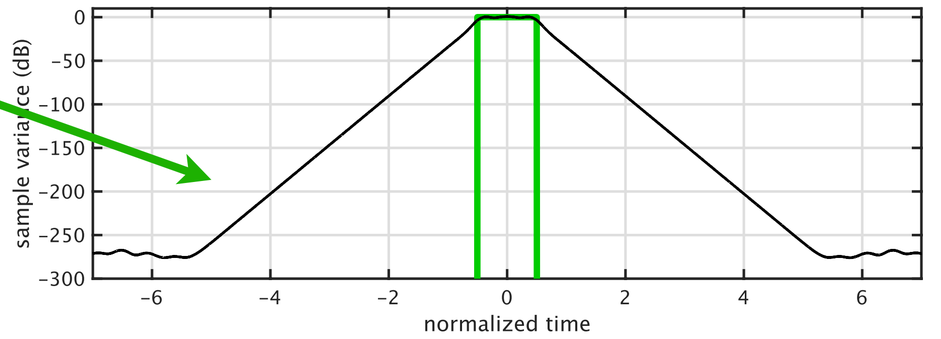

Simultaneous measurement of multi-path is an adoption of our previously proposed method. Video presentation skips details. Please check the reference and use Q & A time for further details.

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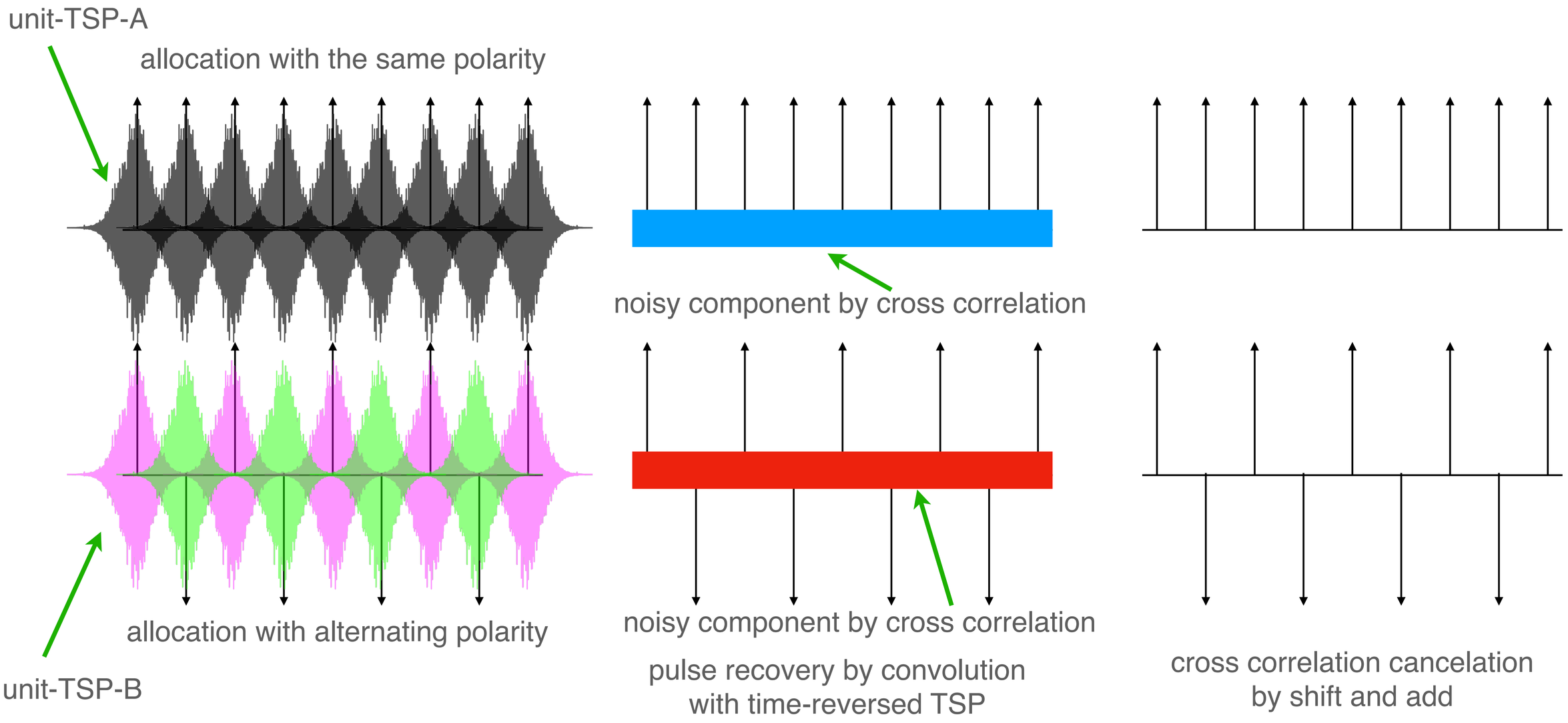
Repetitive allocation of unit-TSPs

How to make sequences orthogonal

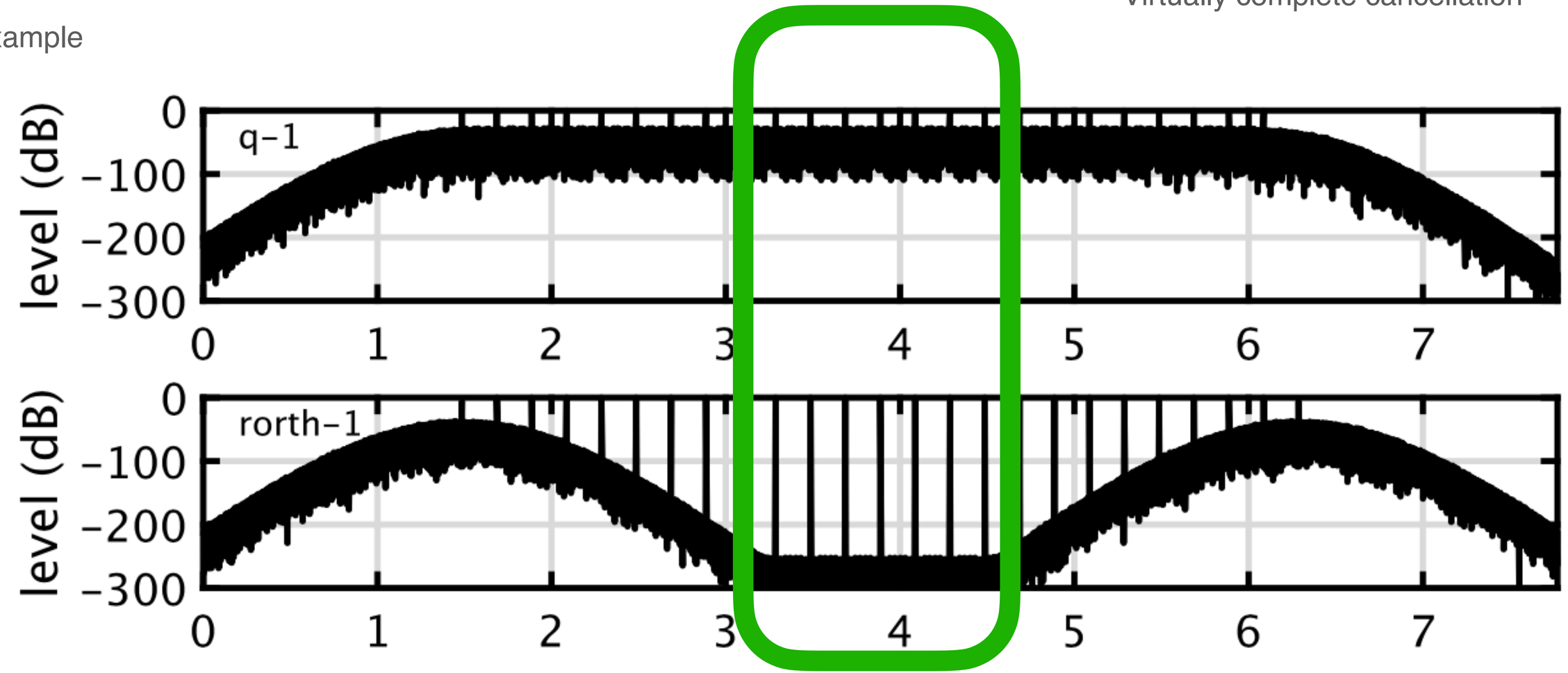


Repetitive allocation of unit-TSPs

How to make sequences orthogonal

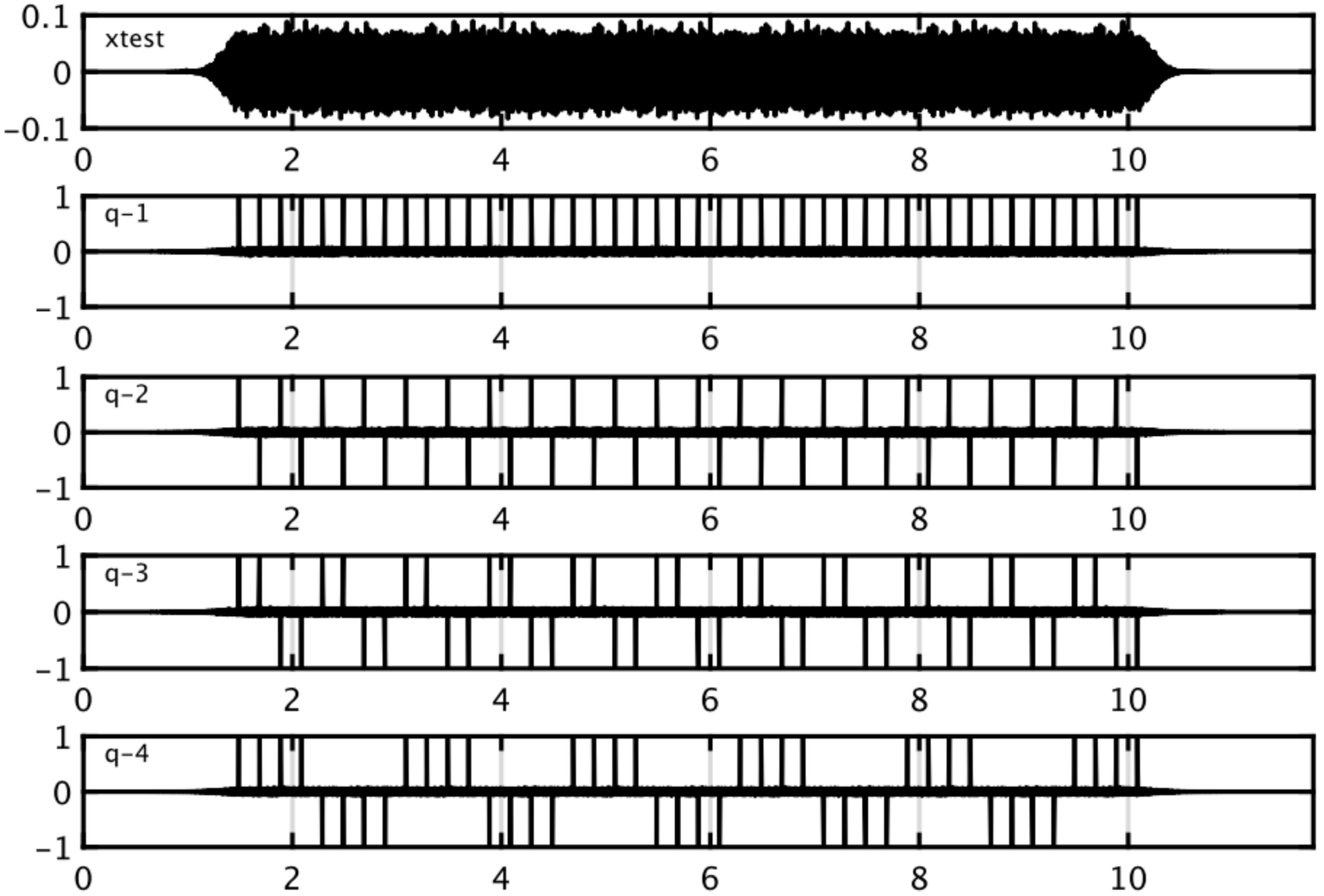
Virtually complete cancellation

Example



Simultaneous measurement

Four orthogonal sequences are special:



Sum of four sequences defined by Eq.(7)

Four types of recovered pulses defined by Eq.(8)

Simultaneous measurement

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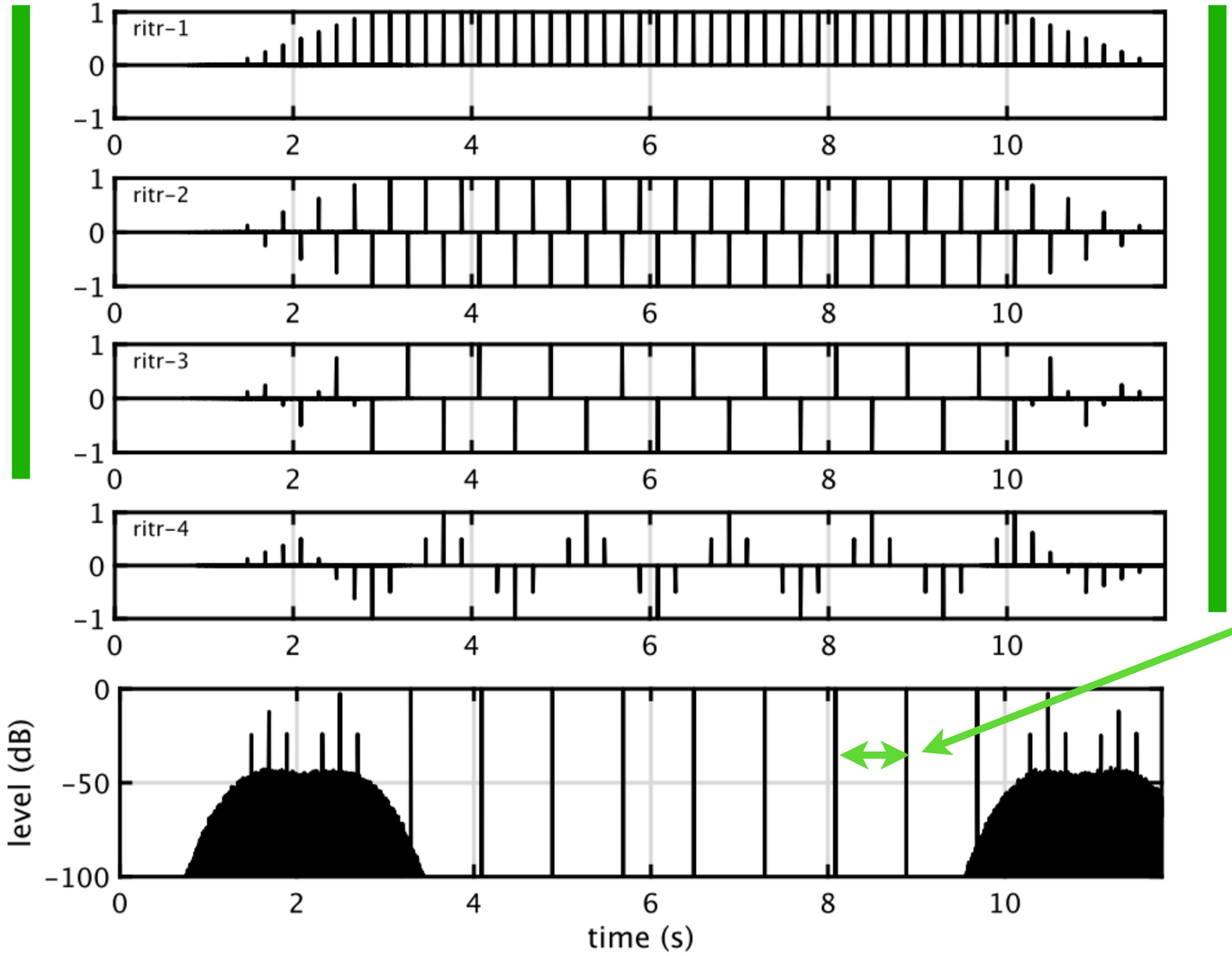

orthogonal sequences Equation (9)

Four-times length of the repetition period

Extended length impulse response Equations (9)-(11)

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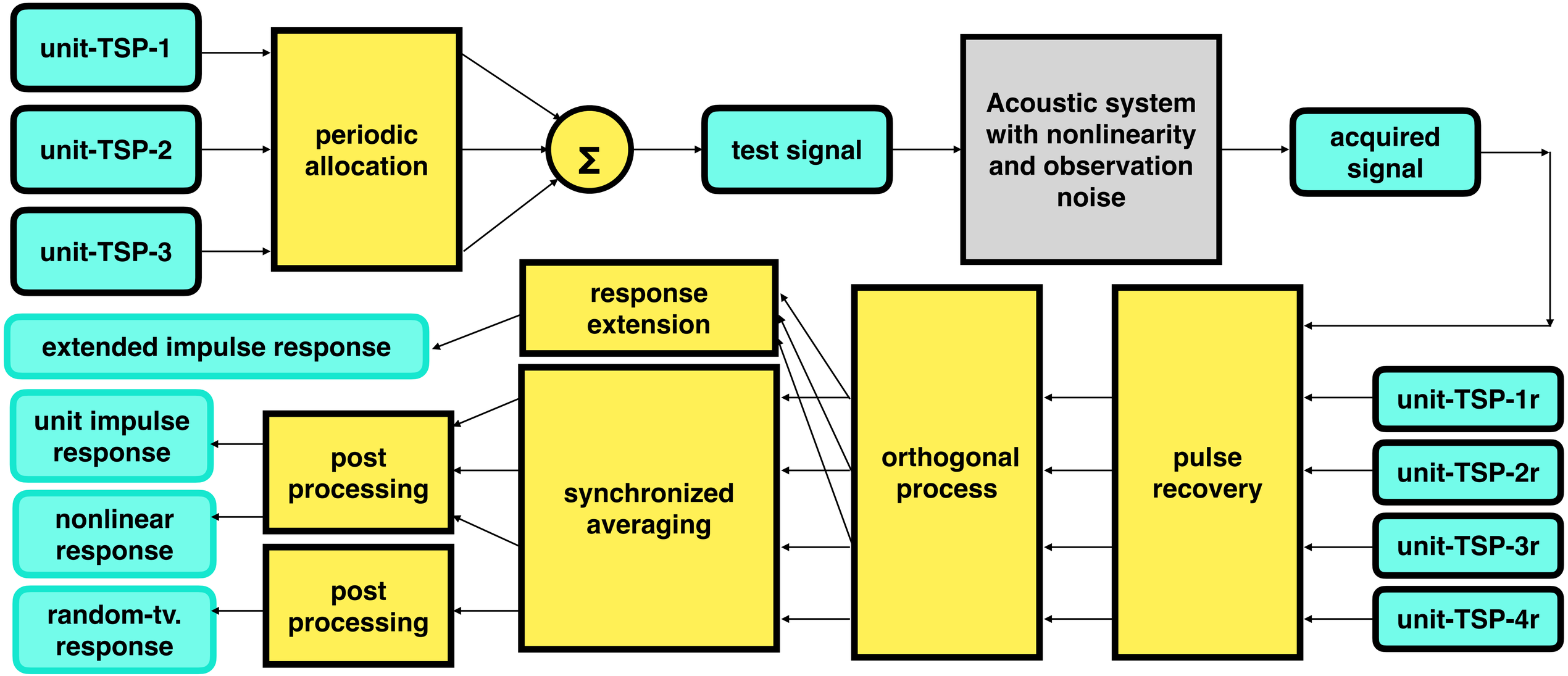
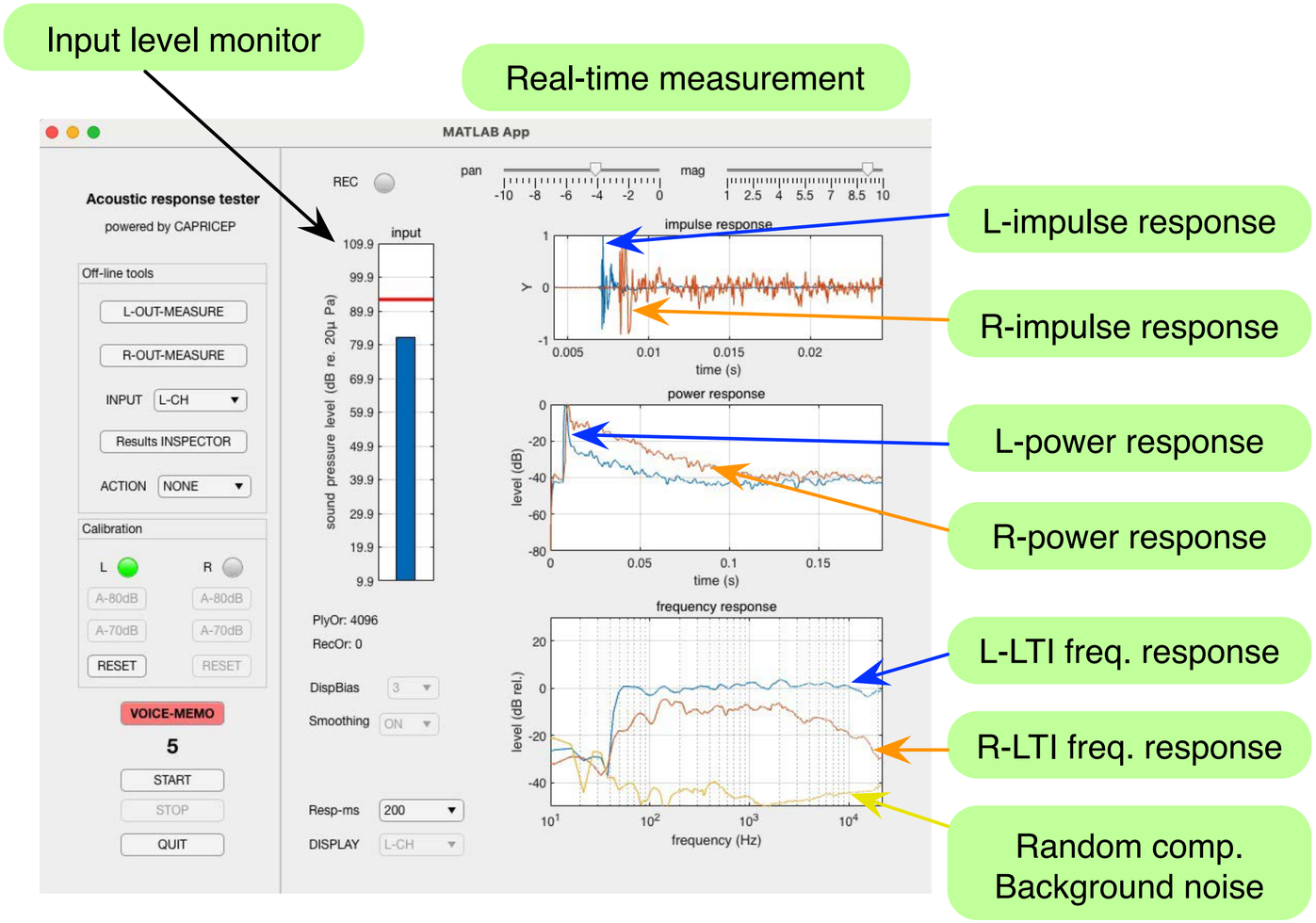
Application to acoustic measurement tool

Combination of three unit-TSPs is especially useful



GUI of an acoustic measurement tool

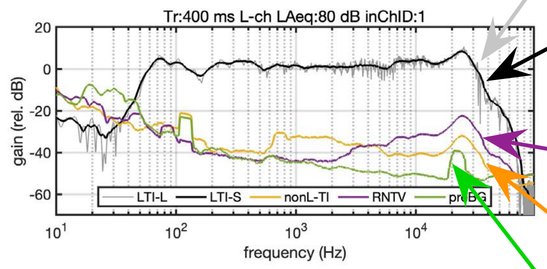
Interactive and real-time simultaneous multi-path measurement



Example report of an acoustic measurement tool

Interactive and real-time simultaneous multi-path measurement

Detailed off-line measurement



LTI-freq. response

LTI-freq. response (1/3 oct smoothing)

Random response

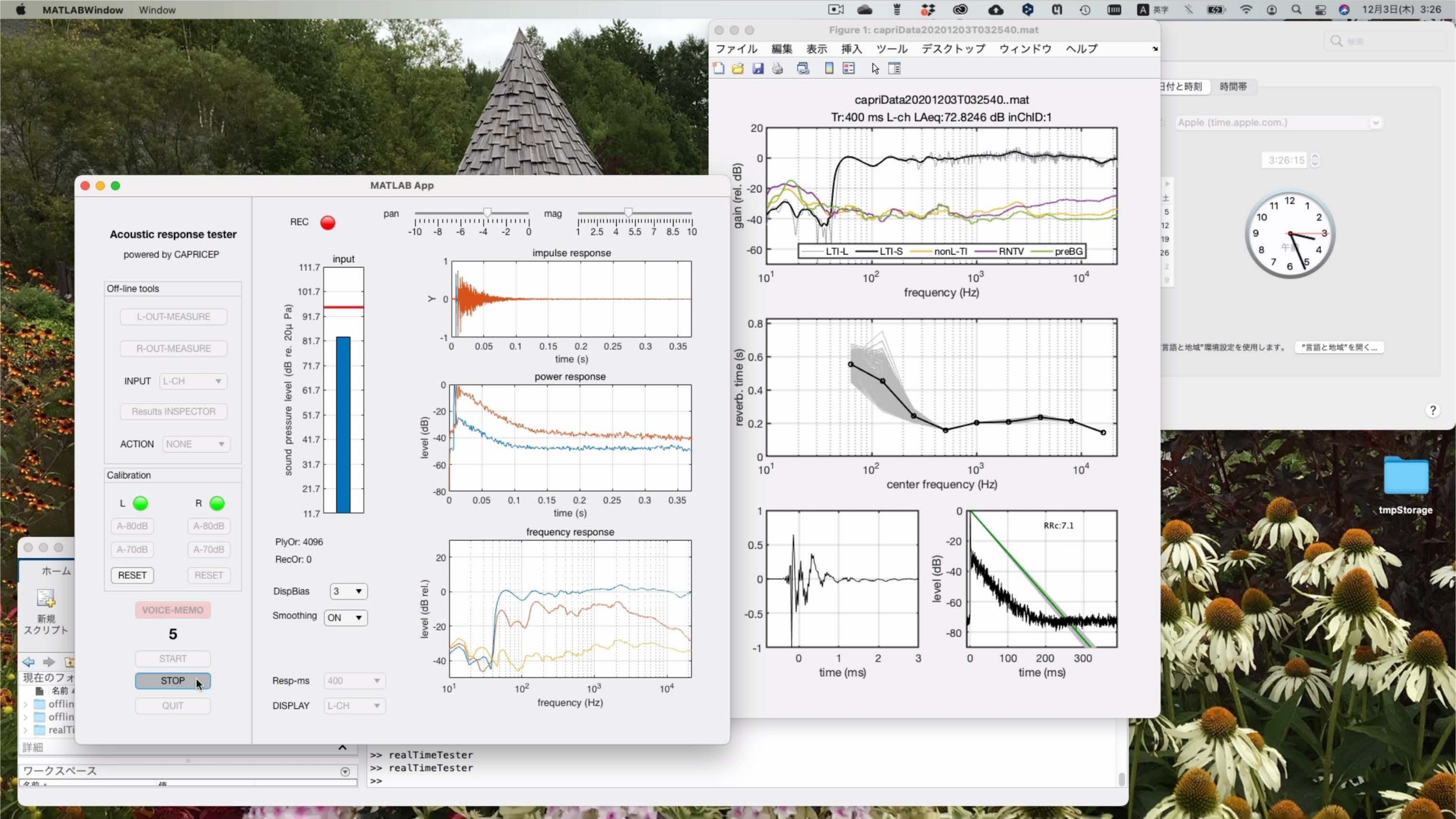
Nonlinear TI-resp.

Background noise

One octave width reverberation time

Critical distance coefficient

Impulse response


MATLABWindow
Window
12月3日(木) 3:26
MATLAB App
Acoustic response tester
powered by CAPRICEP
Off-line tools
L-OUT-MEASURE
R-OUT-MEASURE
INPUT
L-CH
Results INSPECTOR
ACTION
NONE
Calibration
L
R
A-80dB
A-70dB
RESET
VOICE-MEMO
5
START
STOP
QUIT
REC
pan
mag
input
sound pressure level (dB re. 20μ Pa)
impulse response
time (s)
power response
level (dB)
frequency response
level (dB rel.)
frequency (Hz)
PlyOr: 4096
RecOr: 0
DispBias
Smoothing
ON
Resp-ms
400
DISPLAY
L-CH
Figure 1: capriData20201203T032540.mat
ファイル 編集 表示 挿入 ツール デスクトップ ウィンドウ ヘルプ
capriData20201203T032540..mat
Tr:400 ms L-ch LAeq:72.8246 dB inChID:1
gain (rel. dB)
LTI-L
LTI-S
nonL-TI
RNTV
preBG
frequency (Hz)
reverb. time (s)
center frequency (Hz)
time (ms)
RRc:7.1
level (dB)
tmpStorage
>> realTimeTester
>> realTimeTester
>>

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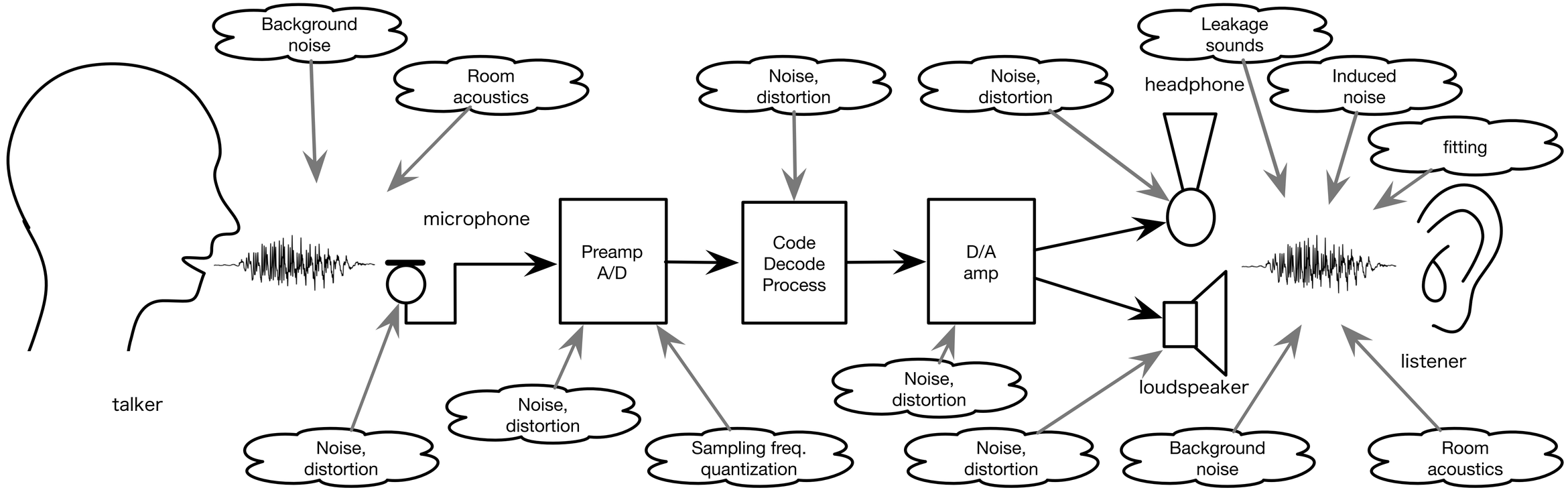
Thank you for your interest!

CAPRICEP

GitHub

Resource

YouTube



Contributing factors in speech material acquisition and presentation environment